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Effects of different orthognatic surgery procedures on pharyngeal airway space: a single center study

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1. Abstract

Aim: The aim of this study is to reveal if different surgical procedures of the upper and lower jaw have an effect on the pharyngeal airway space (PAS). PAS is important considering the obstructive sleep apnea (OSA), since an enlargement or a reduction of the PAS can influence an existing OSA, or even be a risk factor to create an OSA.

Subjects and methods: The sample consisted of pre- and postoperative lateral cephalograms of 18 males and 26 females (mean age 23.25 ± 5.84 years). The inclusion criterion was that all patients had undergone an orthodontic surgery, either a bilateral sagittal split osteotomy (BSSO) or a LeFort 1 osteotomy (LFO) or both. Only patient files, which were used for orthodontic specialization, were included in order to have all the necessary data available. Treating OSA was not an inclusion criterion. Statistics were performed with spearman correlation, One-way ANOVA combined with a Scheffe post-hoc test and a paired t-test.

Results: Diff ANB showed a positive statistically significant correlation to Diff Spp (CC 0.367, p 0.015), as well as a negative statistically significant correlation to Diff Pg (-0.341). A positive statistically significant correlation was found between Diff t and Diff p (0.412).

According to one-way ANOVA there is no evidence that there are differences in Diff p (p= 0.552) and Diff t (p=0.666) with respect to the four groups A, B, C and D.

The paired t-test revealed that there is a change in p measurements between pre- and postoperative time points: 1.4, 95% CI (0.2; 2.6), p=0.022. There is no evidence that there is a change in t measurements between the pre- and postoperative time points: 0.87, 95% CI (-0.2; 1.9), p=0.101

Conclusion: At group level it can be summarized, that an advancement of the lower jaw has on average a positive effect on the airways while the same cannot be said for surgical interventions of the upper jaw.

2. Introduction

A distinction is drawn between obstructive sleep apnea (OSA) and Central sleep apnea (CSA). While OSA is the most common category of sleep-disordered breathing, CSA is a rare condition in the general population, commonly occurs in patients with systolic heart failure (Sin, 1999). CSA is a central nervous system disorder that occurs when the brain signaling for breathing is delayed. CSA can be caused by disease or injury involving the brainstem, such as a stroke, a brain tumor, a viral brain infection, or a chronic respiratory disease. Patients with CSA seldom snore. However, while the causes of apnea are different in CSA and OSA, the symptoms and complications of these two diseases are much the same (Kemp, 2008).

Both epidemiological and sleep clinic-based studies indicate that OSA is more common in men than in women (Ferini-Strambi, 2004). OSA is found in all age groups but its prevalence increases with age. In children, the prevalence of OSA is less well defined and has been estimated to be 2–8%. A subject, based on a random sample of state employees in Wisconsin (USA), showed, that 24% of men and 9% of women had OSA between the ages of 30 to 65 years (Young, 1993).

The apnea-hypopnea index (AHI) is an index of severity that combines apneas and hypopneas. Combining them both gives an overall severity of sleep apnea including sleep disruptions and desaturations (a low level of oxygen in the blood). The apnea-hypopnea index, like the apnea index and hypopnea index, is calculated by dividing the number of apneas and hypopneas by the number of hours of sleep. In general, the AHI can be used to classify the severity of disease (mild 5-15, moderate 15-30, and severe greater than 30).

Among subjects over 55 years of age, 30–60% fulfills the criterion of an AHI > 5 (Krieger, 1980; Carskadon & Dement, 1981; Ancoli-Israel, 1989). In a population of community-dwelling older adults, 70% of men and 56% of women between the ages of 65 to 99 years have evidence of OSA with a criterion of AHI > 10 (Ancoli-Israel, 1991).

2.1. Obstructive sleep apnea

By definition, apneas or hypopneas that last a minimum of 10 seconds are considered clinically significant, although they usually last from 20 to 30 seconds and can last more than one minute (Kryger, 1989). Most of these episodes end when the patient wakes up slightly, almost always without being aware of it. This "arousal response" is caused by hypoxia and is activating the airway dilator muscles. In severe cases, the cycle of opening and closing of the pharynx can recur 400 to 600 times a night (Silverberg, 2002). It is caused by a structural narrowing of the upper airway and is manifested when muscular tone diminishes during sleep, especially in supine position when the tongue falls back (Yu, 1994).

OSA patients can by divided into three subcategories (Partinen, 1988):

- Patients with clear anatomic abnormalities and no significant obesity (Body mass Index (BMI) > 28 and BMI < 33).
- Patients with morbid obesity (BMI > 45) and a few abnormal cephalometric measurements (MP-H, distance from mandibular plane (a plane constructed from gnathion through gonion) to hyoid bone (H); PAS, posterior airway space, defined by Riley and coworkers (1990) as the space behind the base of the tongue and limited by soft tissues.).
- Patients with combined, to a varying degree, increased BMI (>25) and abnormal anatomy.

Many of these patients go unrecognized, with tremendous medical and economic consequences for individual patients and for society (Wiegand & Zwillich, 1994).

2.1.1. Warning signs and symptoms of obstructive sleep apnea

- Frequent silences during sleep due to breaks in breathing (apnea)
- Choking or gasping during sleep to get air into the lungs
- Loud snoring
- Sudden awakenings to restart breathing or waking up in a sweat
- Daytime sleepiness and feeling unrefreshed by a night’s sleep, including falling asleep at inappropriate times
- Increased heart rate and/or blood pressure

A patient's spouse or bed partner may usually describe the sleep behavior much better than the patient itself. It is crucial, therefore, that a bed partner is present during the interview. While patients may report being "a little sleepy", persons who live with patients may describe them as being very sleepy. For example patients who have OSA have a significantly greater chance of having a motor vehicle crash when compared with persons who do not have OSA (Findley & Suratt, 2001).

The reason for the daytime sleepiness is that the patients stop breathing during sleep due to OSA, so that the balance of oxygen and carbon dioxide in the blood is upset. This imbalance stimulates the brain to restart the breathing process. The brain signals to wake up so that the muscles of the tongue and throat can increase the size of the airway. Then, carbon dioxide can escape, and oxygen can enter the airway. These waking episodes are necessary to restart breathing and are not remembered but do disrupt sleep and cause daytime exhaustion (Hoe Bing, 2005).

2.1.2. Causes and risk factors of obstructive sleep apnea

Individuals with decreased muscle tone, increased soft tissue around the airway, and structural features that give rise to a narrowed airway like a long soft palate, shallow palate arch, large base of tongue, narrow mandibular arch and mandibular deficiency are at high risk for obstructive sleep apnea (Yu, 1994). Men, whose anatomy is typified by increased body mass in the torso and neck, are more typical sleep apnea sufferers, especially through middle age and older. Adult women suffer typically less frequently and to a lesser degree than men do, owing partially to physiology, but possibly to emerging links to levels of progesterone. Prevalence in post-menopausal women approaches that of men in the same age range.

Primary causes and risk factors of obstructive sleep apnea for adults and children:

- Being overweight or obese (BMI >25) (Murugan & Sharma, 2008).
- Large palatine tonsils (Dahlqvist, 2007).
- Adenotonsillar hypertrophy (Benninger, 2007).
- Other distinctive physical attributes (deviated septum (Balcerzak, 2007), shape of head and neck, receding chin, enlarged tongue (Dahlqvist, 2007))
- Nasal congestion or blockage (from cold, sinusitis, allergies, smoking, etc.) (Carskadon, 1997). The AHI is greater in patients with seasonal rhinitis when symptomatic compared to symptom-free periods, which suggests a role for nasal congestion in OSA (McNicholas, 1982).
- Throat muscles and tongue relax more than normal during sleep (possibly due to alcohol, sedatives or age).
- Gender. Males have roughly twice the risk of OSA as females (Schwab, 1990). Female Hormones appear to have a protective role whit respect to OSA. Population-based studies show that postmenopausal women have a 2-3 fold increased risk of OSA compared to premenopausal women not accounted for by BMI, age, or other risk factors (Young, 2003; Shahar, 2003).
- Smoking. Smoking appears to increase the risk for OSA. This could possibly be through its interference with sleep stability in addition to smoking-related airway inflammation (Al Lawati, 2009).

Obstructive sleep apnea does seem to run in families, which may be a result of anatomic abnormalities, or medical conditions that are genetic. Although it has been recognized for a long time, that there is a hereditary component to the obstructive sleep apnea, identifying its genetic basis remains elusive (Riha, 2008).

2.1.3. Effects of obstructive sleep apneas on health

Sleep apnea has serious health consequences and can even be life-threatening. The main effects of sleep apnea are sleep deprivation and oxygen deprivation.

Sleep deprivation

Deficits in daytime performance due to sleep loss are experienced universally and associated with a significant social, financial, and human cost. Micro sleeps, sleep attacks, and lapses in cognition increase with sleep loss as a function of state instability. Excessive sleepiness and altered circadian rhythms may negatively affect ability to learn, employment, and interpersonal relations, and directly degrade quality of life (Lopes & Esteves, 2008). Other research suggests chronic sleep restriction may also influence cardiovascular and metabolic health (Spiegel, 1999).

Oxygen deprivation

When the patient stops breathing, the brain does not get enough oxygen. Serious problems can result from the oxygen deprivation of sleep apnea, including heart disease like cardiac arrhythmias and bradycardia**,** and high blood pressure, sexual dysfunction, and learning/memory problems (Tangugsorn, 1995).

Cardiovascular disease

Obstructive sleep apnea is an increasingly common disorder and it is a novel cardiovascular disease risk factor. Although the exact mechanism linking sleep apnea with cardiovascular disease is unknown, there is evidence that obstructive sleep apnea is associated with a group of proinflammatory and prothrombic factors that are also important in the development of atherosclerosis (Drager, 2009). Repetitive apneas and hypopneas during sleep are accompanied by hypoxia, increased sympathetic activity and frequent arousals (Lam, 2009). Sleep apnea has clearly been demonstrated to be an independent risk factor for development of hypertension and it has also been implicated in the pathogenesis of atherosclerosis, congestive heart failure, pulmonary hypertension, cardiac arrhythmias and stroke (Dunai, 2006).

Cor pulmonale (congestive heart failure)

The most serious consequence of untreated obstructive sleep apnea is to the heart. In severe and prolonged cases, there are increases in pulmonary pressures that are transmitted to the right side of the heart. This can result in a severe form of congestive heart failure (cor pulmonale) (Dorasamy, 2007).

Essential hypertension

Hypertension is another major indicator of the presence of OSA. About one half of patients with Essential Hypertension (EH) have OSA, and about one half of all patients with OSA have EH. In fact, in the last two years, seven major studies have shown that OSA is an independent risk factor for hypertension and, generally, the more severe the OSA, the more prevalent and severe the hypertension (Silverberg, 2002).

Cardiac arrhythmias

Most of the patients with obstructive sleep apnea have nocturnal bradycardia (5-50%), paroxysmal tachyarrhythmia (atrial 35%; ventricular 0-15%), or both. The frequency of rhythm disturbances associated with the severity of the sleeping disorder. It is important to recognize the factors predisposing to arrhythmias and the early appropriate therapy of patients is essential, in order to protect patients from life threatening arrhythmias which may worsen the clinical outcome (Barta & Szabo, 2008).

Stroke

Patients with OSA were not more likely to die or experience a myocardial infarction than were individuals without OSA, but, after adjusting for potential confounders, patients with OSA were approximately three times more likely to experience a new stroke. Furthermore, there was a dose-response effect, with patients who had mild OSA and those who had severe OSA being 2.4 times and 3.6 times more likely to experience stroke, respectively (Calvin and Somers 2008).

2.1.4. Depression and sleep apnea

There have been reports that depressive symptoms can be associated with sleep disorder. A number of investigations have addressed this issue. Although some have found no correlation, most studies have concluded that there is an association between OSA and depressive symptoms (Schroder & O'Hara, 2005). Other investigations have shown that depressive symptoms improve with treatment of OSA, and that untreated OSA may contribute to treatment resistance in some cases of mood disorders. Within the framework of current psychiatric diagnostic criteria, the depressive symptoms associated with OSA can be viewed as a combination of a mood disorder secondary to a primary medical condition and an adjustment disorder with depressed mood. The question of whether OSA causes depressive symptoms can perhaps be best answered by viewing OSA and depression as having certain symptoms that are common to both disorders (Baran & Richert, 2003).

2.1.5. Diagnosing obstructive sleep apnea

Diagnosis is often based on a combination of lab tests and patient history. Clinically OSA is suspected when a patient presents with both snoring and excessive daytime sleepiness (Verhulst, 2008).

Polysomnography

The diagnosis of OSA is confirmed when a polysomnography recording determines an Apnea-Hypopnea-Index (AHI) of >5 per hour of sleep (The Report of the American Academy of Sleep Medicine Task Force, 1999). Even if cutoff points have never been clearly defined, an AHI of less than 5 is generally considered being normal, 5–15 mild, 15–30 moderate and over 30 severe OSA (Schroder and O'Hara 2005).

An "event" can be either an apnea, characterized by complete cessation of airflow for at least 10 seconds, or a hypopnea in which airflow decreases by 50 percent for 10 seconds or decreases by 30 percent if there is an associated decrease in the oxygen saturation or an arousal from sleep. To grade the severity of sleep apnea, the number of events per hour is reported as the apnea-hypopnea index (AHI) (American Academy of Sleep Medicine Task Force, 1999).

2.2. Treatment for obstructive sleep apnea

Minor sleep apnea is responsive to self-help remedies, or “behavioral treatments”. These are some of the following self-help treatments for obstructive sleep apnea:

- Lose weight. Weight reduction has been shown to be effective in improving the symptoms and severity of several respiratory diseases, including OSA and asthma (Murugan & Sharma, 2008).
- Stop using alcohol, tobacco, and sedatives, or anything that relaxes the muscles of the throat and encourages snoring. The avoidance of alcohol and other central nerve system depressants is generally recommended (Topfer, 2008).
- Sleeping in the side. Special pillows or remedies that encourage side sleeping, such as the “tennis ball trick,” might help people who only experience sleep apnea when they sleep on their back. A 'Positioner' preventing sleeping on the back can effectively reduce obstructive sleep apnea (Loord & Hultcrantz, 2007).

In most cases these procedures are not efficient enough; therefore doctors often recommend continuous positive airway pressure (CPAP), in which a facemask is attached to a tube and a machine that blows pressurized air into the mask and through the airway to keep it open.

2.2.1. Continuous Positive Airway Pressure

Continuous Positive Airway Pressure (CPAP) is the most widely recommended treatment for moderate to severe obstructive sleep apnea (McDaid, 2009). CPAP entails wearing a mask-like device while you sleep, which provides pressurized air to prevent the airway from collapsing. Most CPAP units are the size of a tissue box and many now come with a built in humidifier for comfort.

While CPAP works very well in preventing apnea symptoms, many people find the apparatus uncomfortable and difficult to use. Luckily, recent advancements to CPAP technology have made these once cumbersome devices much lighter, quieter and much more comfortable.

Recent refinements including options such as:

-"bi-level PAP", which switches from higher to lower air pressure during the exhalation, making breathing easier for some.

-"Auto PAP", which uses an internal regulator that adjusts pressure rather than remaining at one fixed setting (Abad, 2009).

In patients with OSA of varying severity, there is evidence that nasal CPAP (compared with no nasal CPAP) reduces objective daytime sleepiness (in patients with moderate to severe disease), improves some measures of cognitive performance, reduces symptoms, reduces depression, and improves perceptions of quality of life, energy and vitality. These effects have been demonstrated over the short to medium term (Effectiveness of nasal continuous positive airway pressure (nCPAP) in obstructive sleep apnea in adults; National Health and Medical Research Council, 2000).

2.2.2. Oral appliances for obstructive sleep apnea

Oral appliances (OA) are an alternative to continuous positive airway pressure for the treatment of obstructive sleep apnea. Although CPAP is a highly efficacious treatment, there is a need for other treatment options because the clinical effectiveness of CPAP is often limited by poor patient acceptance and tolerance, and suboptimal compliance (Chan, 2009).

Until there is more definitive evidence on the effectiveness of OA in relation to CPAP, with regard to symptoms and long-term complications, it would appear to be appropriate to recommend OA therapy to patients with mild symptomatic OSA, and those patients who are unwilling or unable to tolerate CPAP therapy (Lim, 2004).

2.2.3. Surgical intervention

A number of different surgical interventions are available to improve the size or tone of a patient's airway. For decades, tracheotomy was the only effective treatment for sleep apnea. It is used today only in rare, intractable cases that have withstood other attempts at treatment. Modern operations employ one or more of several options, tailored to each patient's needs. Today, the most important surgery is the Maxillomandibular advancement (MMA). For years, the reported efficacy of MMA for the treatment of obstructive sleep apnea (OSA) was uncertain. But recently some studies showed that MMA is a safe and highly effective treatment for OSA (Holty, 2009).

While CPAP is an extremely effective form of therapy, there are two pitfalls in its use. It is not a permanent cure; when patients stop treatment, OSA returns within a few days (Kakkar, 2007). Secondly, because patients may be reluctant to attempt CPAP or persist in using it, family physicians should encourage and closely follow patients because the beneficial effects on quality of life can be great (Hudgel 1996; Davies & Stradling 2000).

- Nasal surgery, including turbinectomy (removal or reduction of a nasal turbinate), or straightening of the nasal septum, in patients with nasal obstruction or congestion, which reduces airway pressure and complicates OSA. It is shown in a study, that nasal surgery has a limited efficacy in the treatment of adult patients with sleep apnea. Nevertheless, nasal surgery significantly improves sleep quality and daytime sleepiness independent of the severity of obstructive sleep-related breathing disorders (Verse, 2002).
- Tonsillectomy and/or adenoidectomy in an attempt to increase the size of the airway. Particularly in pediatric OSA, adenotonsillectomy and tonsillectomy are the most common treatments and are highly effective (Verse, 2008).
- Removal or reduction of parts of the soft palate and some or the entire uvula, such as uvulopalatopharyngoplasty (UPPP) or laser-assisted uvulopalatoplasty (LAUP). Modern variants of these procedures sometimes use radiofrequency waves to heat and remove tissue. UPPP is widely used as a first-step procedure for the surgical management of obstructive sleep apnea (OSA) syndrome but best manages obstruction occurring at the level of the oropharynx alone and not the hypopharynx (Senior, 2000).
- Reduction of the tongue base, either with laser excision or radiofrequency ablation. For patients suffering from severe obstructive sleep apnea syndrome in whom the most obvious morphological alteration is the presence of hypo-pharyngeal obstruction due to tongue base hypertrophy, who are overweight or suffering from moderate obesity, a surgical procedure aimed at reducing tongue volume and at repositioning the hyoid bone, even if invasive, leads to a favorable outcome (Sorrenti, 2004).

- Genioglossus bone advancement technique (GBAT), in which a small portion of the lower jaw that attaches to the tongue is moved forward, to pull the tongue away from the back of the airway. Genioglossus muscle advancement using the GBAT system is a safe, simple, and rapid method for improving symptomatic base of tongue obstruction in sleep-disordered breathing (Lewis & Ducic, 2003).
- Hyoid suspension, in which the hyoid bone in the neck, another attachment point for tongue muscles, is pulled forward in front of the larynx. But hyoid suspension does not provide results equivalent to those reported for genioglossus advancement or multisession tongue radiofrequency. Hyoid suspension alone is not an efficacious treatment for hypopharyngeal airway obstruction in most patients with obstructive sleep apnea (Bowden, 2005).
- **Maxillomandibular advancement (MMA).** Although standard treatment of OSA is the CPAP-therapy, in some patient this therapy fails or is not well accepted. In these cases, bimaxillary advancement in adults is a safe and successful surgical technique for an immediate improvement in OSA (Kessler, 2007). Several teams have advocated it as a standard surgical treatment for severe OSA after failure of CPAP because it provides a high success rate ranging from 80-97 percent (Riley, 1993; Hochband, 1994; Prinsell, 2002). MMA is able, in 80 percent of cases, to bring the patient to within normal or close to normal apnea hypopnea indexes (surgical success outcome AHI <20/h and 50% reduction of preoperative AHI) (Blumen, 2009).

  But still, MMA is considered to be a „highly morbid“ surgical procedure because the operation can take several hours and carries a risk of postoperative dyspnea due to pharyngeal edema (Li, 2001). The mandibular advancement must be greater than 10mm (Hochban, 1994) and this level of advancement could be responsible for dental and temporomandibular joint complications and could modify the middle and lower third of the face (Bettega, 2000; Li, 2000; Li, 2001).

2.3. Orthognathic surgery procedures

The role of surgery in the treatment of OSA has been questioned repeatedly as the long-term success rate of the procedures has come into question (Pirsig, 2000). Surgery is generally only effective in obstructive sleep apnea where the obstruction can be effectively removed. The patient's age, weight and other factors may make them a bad candidate for surgery (Randerath, 2011). In order to achieve a high success rate it is an absolute necessity to carefully take down the medical history of the patient and inform adequately on all therapeutically options (Blumen, 2009). It is crucial to determine the patient's motivation, as compliance is the deciding factor for the outcome of the treatment (Maurer, 2010).

Many sleep specialists still regard continuous positive air pressure (PAP or CPAP) treatment as the gold standard (Sundaram, 2005). But upper airway surgery is an important treatment option for patients with OSA, particularly for those who have failed or cannot tolerate conservative methods like positive airway pressure therapy (Won, 2008).

In cases of dentofacial deformities at full-grown adults, one of the possible treatments is orthognathic surgery. These surgical procedures not only have an influence on the facial appearance, it changes the posterior airway space (PAS) as well (Doff, 2009). Advancement of the maxilla and mandible causes widening of the airway in both the anteroposterior and lateral dimension. This effect would lead to better airflow and decreased airway resistance. This is supported by the evidence showing high success rates when orthognathic surgery, especially maxillomandibular advancement (MMA), is utilized to treat OSA (Lye, 2008).

On the other hand, there is an apprehension, that maxillomandibular setback might lead to or amplify an already existent OSA. Especially patients with obesity, potential sleep-disordered breathing and a large amount of setback may suffer from obstructive sleep apnea (OSA) after the surgery (Kitagawara, 2008).

Risk of narrowing the hypopharyngeal airway space after surgery, causing setback of the tongue and increasing a patient’s tendency for snoring and development of an obstructive sleep apnea syndrome has been greatly reduced by frequent use of bimaxillar surgery. When dealing with patients that have a big tongue, the guidelines today recommend anterior advancement of the maxilla to achieve occlusal harmony (Hasabe, 2011).

Orthognathic surgery has become very popular in maxillofacial surgery over the last 30-40 years. It comprises several surgical procedures that allow the repositioning of the entire mid-face, mandible and the dentoalveolar segments to their desired locations. These procedures can be either carried out as isolated osteotomies or in various combinations. One aspect of this surgery is the effect of the skeletal movements on the posterior airway space (Hasebe, 2011).

Dislocation of 14-15mm of either maxilla or mandible is possible (Goodday, 2009). However in major dislocation surgery, the risks of relapse as well as the potential for instability increase ("Mund-Kiefer-Gesichtschirurgie", Herausgegeben von Hans-Henning Horch, Elsevier GmbH Urban & Fischer, München, Dezember 2006). Also the clinician should ensure that the objective of treating the abnormal airway is not made at the cost of poor aesthetics. The movement of abnormal structures into a more normal position should result in a favorable change in terms of the facial appearance (Goodday, 2008). Surgical dislocation of the maxilla of over 10mm calls for the use of autograft bone material transplant or artificial bone material to bridge the gap (Goodday, 2009).

2.3.1. Class III deformity surgery

Class III skeletal deformity is the result of mandibular prognathism or maxillary deficiency (Samman, 1992). Class III malocclusion is far more prevalent in Asia than in Caucasian (Graber & Mosby, 2005). Accordingly, Class III malocclusions account for a large proportion of orthodontic patients in these countries—for example, 33 percent of orthodontic patients in Japan and 20 percent in China (Fu, 2002). In contrast, the prevalence of class III malocclusion in the United States is only about 1 percent of the total population, and only 5 percent of orthodontic patients (Graber & Mosby, 2005). A severe class III skeletal relationship poses both aesthetic and functional problems. Its correction would involve both orthodontic and orthognathic treatment of the airway.

The orthognathic surgeries commonly used to correct this deformity are the mandibular setback and the maxillary advancement procedures.

Mandibular setback

Bilateral sagittal split osteotomy (BSSO) is the most common mandibular setback procedure. Its popularity is due to its versatility in correcting mandibular abnormalities. Surgeons first noticed some patients developing OSA following mandibular setback and published case reports about this possible complication (Guilleminault, 1985; Riley, 1987; Liukkonen, 2002). The isolated mandibular setback has been the target of several studies. These studies reported a change in the position of the hyoid bone and reduction in the dimensions of the retrolingual and hypopharyngeal airway after mandibular setback surgery (Liukkonen, 2002). All these studies were cephalometric studies that only assessed the 2-dimensional anteroposterior changes of the airway. Despite this, the results are still relevant as Riley and Powell (1990) showed a significant correlation between the pharyngeal airway space measured on the cephalographs and the volume of the airway calculated from computed tomography. Some studies suggested that the changes are temporary as the tissues re-adapt, resulting in partial or total resolution.

However, most of the other studies showed that the airway changes are stable over the long term. The study with the longest follow-up of 12 years showed that the decrease in the lower pharyngeal airway was stable but the upper and middle pharyngeal airway continued to decrease over the 12 years (Eggensperger, 2005).

Bimaxillary surgery

With advances in knowledge and techniques, corrective surgery progressed to include bimaxillary procedures. In the last decade, mandibular setback surgery only declined in frequency to fewer than 10% of Class III patients, whereas bimaxillary surgery is used in about 40% of Class III patients (Busby, 2002).

Contrary to logic deduction, the addition of the maxillary advancement may not result in an increase in the retropalatinal dimension. In 2 studies, bimaxillary surgery was performed to treat the Class III skeletal deformities and the authors found that there was still a significant reduction in the retropalatinal dimension (Samman, 2002; Turnbull, 2000). Another study showed that the bimaxillary surgery group resulted in the reduction of the retropalatinal dimension but it was not significant after 2 years. Also, it was to a much lesser degree than the group, which only had mandibular setback (Chen, 2007).

This was postulated to be due to 2 key issues. Firstly, maxillary advancement results in adaptive changes of the soft palate in order to maintain velopharyngeal seal and palatal function (Schendel, 1979). The second matter concerns the posterior and superior movement of the tongue from the mandibular setback, which comes into contact and displaces the soft palate backwards and upwards (Lye, 2008). Combining the 2 factors, the soft palate becomes longer and thinner and the palatal angle increases. Therefore, the maxillary advancement may not gain a significant enlargement of the retropalatinal dimension and coupled with the mandibular setback, there may even be a narrowing of the retropalatinal airway (Lye, 2008).

However, it is still better to decrease the magnitude setback by performing simultaneous maxillary advancement to prevent the development of OSA (Hoekema, 2003) assuming that bimaxillary surgery might have less effect on reduction of the pharyngeal airway space than mandibular setback surgery only (Chen, 2007).

LeFort I surgery

The use of a LeFort I osteotomy to correct maxillary deformity was first described by Obwegeser in 1969. During the 1970s, the procedure became increasingly popular because it can be used to manage discrepancies in all 3 planes of space (Bell, 1975). This versatility, in addition to few side effects, has made the LeFort I osteotomy the procedure of preference for the treatment of many skeletal Class III patients. Esthetic considerations have also contributed to the increasing use of this approach (Proffit, 1991).

Due to soft tissue, the distance of sagittal dislocation of the maxilla is limited. The standard LeFort I osteotomy according to the LeFort I fracture lines were modified several times by numerous authors to achieve different possibilities for the fixation. The LeFort I osteotomy main complication is intra- or postoperative bleeding. But progress in surgical procedures as well as technical development has significantly reduced the risk of major bleeding, so that today, a LeFort I osteotomy has a lower potential for complications than the bilateral sagittal split osteotomy. Therefore LeFort I osteotomy is currently the standard operative procedure for Class III deformity ("Mund-Kiefer-Gesichtschirurgie", Herausgegeben von Hans-Henning Horch, Elsevier GmbH Urban & Fischer, München, Dezember 2006).

2.3.2. Class II deformity surgery

According to epidemiological surveys, Angle Class II, Division 1 malocclusion is the most frequent form of malocclusion in Caucasian (Tammoscheit, 1996).

The Asian population has been shown to have about 22.4% of class II/2 and 26.3% of class II/1 malocclusions (Soh, 2005). This is less than our Caucasian population where 35% of the people have severe overjet and anteroposterior discrepancy (McLain, 1985).

The main component of this deformity is usually the mandibular deficiency (McNamara, 1981) with infrequent maxillary protrusion. The milder cases can be treated with growth modification and orthodontic camouflage, while the severe ones need orthognathic surgery. A large proportion of such surgery is directed at the advancement of the mandible and a much lesser extent at maxillary setback. In this group of patients, we are worried that they may already have snoring or OSA, as this deformity has already been shown to be a possible clinical feature of an OSA patient.

Kuo (1979), Bear and Priest (1980) were the first to document that surgical advancement of the mandible improved OSA. Turnbull and coworkers (2000) found that the advancement improved the retropalatinal and retrolingual dimension of the airway significantly. Furthermore, there was increased intermaxillary space and decreased tongue proportion. This was also confirmed by several authors who noted an increase in the PAS after mandibular advancement (Farole, 1990; Yu, 1994). Powell and coworkers (1983) were among the first to report the use of mandibular advancement for the treatment of OSA. Mehra (2001) assessed the pharyngeal airway space changes with anterior rotation of the maxillomandibular complex and found it a useful tool to complement maxillomandibular advancement in patients with high occlusal plane (mandibular retrognathism).

Maxillomandibular advancement (MMA)

Maxillomandibular advancement is described as the advancement of the maxilla and mandible via the LeFort I and bilateral sagittal split osteotomies. It was mentioned as a treatment regime for OSA by Waite and Riley (Waite, 1989; Riley, 1990). In this study, they reported the largest MMA series, in which 98% of the patients with OSA (89 of 91) were treated successfully, based on a postoperative AHI of less than 20% or a greater than 50% reduction in AHI. There it is described as the advancement of the maxilla and mandible via the LeFort I and bilateral sagittal split osteotomies.

MMA surgery pulls forward the anterior pharyngeal tissue attached to maxilla, mandible and hyoid to structurally enlarge the entire pharyngeal airway space.

MMA is the most successful (excluding tracheotomy) acceptable surgical treatment for OSA, with a therapeutic efficacy equal to that of CPAP (Prinsell, 2002). MMA is so successful because it actually increases the space of the upper airway at many levels. An anterior movement of the maxilla and mandible draws the base of the tongue and soft palate forward. By doing so, the surgery effectively opens the nasal valve and improves nasal airflow. MMA has been shown to reduce upper airway resistance by nearly two thirds (Louise, 2007).

Mandibular advancement

Over the last decade, mandibular advancement (MA) has emerged as an alternative therapy for various degrees of OSA (Kushida, 2006), including severe OSA in children (Schlessl, 2008). Advancement of the mandible has been shown to improve velopharyngeal airway patency and to reduce upper airway collapsibility (Ryan, 1999; Ng, 2003). Blumen (2010) showed in his study a surgical successful outcome of 80% and 52% of the patients reached a postoperative AHI ≤ 10. In comparison to CPAP, MA devices were less effective in reducing AHI, but were preferred over CPAP in many studies (Engelman, 2002).

3. Subjects and methods

This study was designed to retrospectively assess the differences in the amount of sagittal forward or backward movements after orthodontic surgery and their influence on the airway space.

3.1. Subjects

In this single center study the data of 45 non-growing adult patients (average age at the time of surgery 23.15 years) were retrospectively obtained from the archives at the Clinic for Orthodontics and Pediatric Dentistry of the University of Zurich, Switzerland. The criterion for inclusion was that all patients had undergone an orthodontic surgery; either bilateral sagittal split (BSSO), or LeFort 1 osteotomy (LFO) or both. Although it was a single center study, different surgeons and orthodontist were involved. Only patient files, which were used for orthodontic specialization, were included, in order to have all the necessary data available. From more than 600 cases over the last 30 years, 45 cases met the selection criteria. No data concerning OSA was available and therefore a history of OSA was no inclusion criterion or aim of the surgical intervention. All patients have undergone surgery to correct skeletal prognathism or retrognathism respectively. Treating OSA was not the reason for the operations. The cases where divided up into four different groups (Table 1):

Class III, BSSO + LFO (Group A)

This group contains 12 patients (7 females and 5 males, average age at the time of surgery 23.41 years) with a skeletal Class III malocclusion (maxillary retrognathism) that was treated by a combined maxillomandibular surgery. In this cases the bilateral sagittal split osteotomy (BSSO) and the LeFort 1 osteotomy (LFO). Additionally 7 out of these 12 patients also had a chin reconstruction surgery.

Class III, LFO (Group B)

These 11 patients (5 females and 6 males, average age at the time of surgery 20.98 years) with a skeletal Class III malocclusion (mandibular prognathism) had undergone a bilateral sagittal split osteotomy (BSSO). One patient out of 11 also had chin reconstruction surgery.

Class II, BSSO + LFO (Group C)

13 patients (11 females and 2 males, average age at the time of surgery 25.08 years) belong to group C. They all showed a skeletal Class II malocclusion (maxillary prognathism) and where treated whit a bilateral sagittal split osteotomy (BSSO) in combination with a LeFort 1 osteotomy (LFO). Chin reconstruction surgery was completed in 9 out of 13 cases.

Class II, BSSO (Group D)

The last group contains 8 patients (4 females and 4 males, average age at the time of surgery 23.07 years) with a skeletal Class II malocclusion (mandibular retrognathism). These patients had undergone only a bilateral sagittal split osteotomy (BSSO), 4 out of 8 had an additional chin reconstruction surgery.

These 45 patients with natural dentition and good-quality initial record (T1) and end of active orthodontic treatment (T2) lateral cephalograms were included for the investigation.

Table 1: Patient groups according to orthognatic surgical treatment

	Skeletal class III		Skeletal class II	
Group	A	B	C	D
	Bilateral sagittal split (BSSO) and LeFort 1 osteotomy (LFO)	LeFort 1 osteotomy (LFO) (maxillary advancement)	Bilateral sagittal split (BSSO) and LeFort 1 osteotomy (LFO)	Bilateral sagittal split (BSSO) (mandibular advancement)
Numbers	12	11	13	8
Gender	6 females, 6 males	5 females, 6 males	11 females, 2 males	4 females, 4 males
Numbers of chin reconstruction surgery	7 (58%)	1 (9%)	9 (69%)	4 (50%)
Average age orthodontic surgery [years]	23.41 (min. 16.93; max. 33.78)	20.98 (min. 17.17; max. 30.36)	25.08 (min. 18.60; max. 39.40)	23.07 (min. 17.18; max. 33.92)
Average treatment time (T1- T2) [years]	±2.84 (min. 1.44; max. 5.41)	±2.61 (min. 1.60; max. 4.20)	±2.62 (min. 1.54; max. 3.99)	±3.15 (min. 1.67; max. 8.16)
Average age at the beginning of treatment [years]	± 21.33 (min. 14.44; max. 32.12)	± 18.91 (min. 14.79; max. 28.78)	± 23.01 (min. 16.56; max. 37.84)	± 21.06 (min. 15.68; max. 31.44)
Average time between orthodontic surgery and end of treatment [years]	± 0.76 (min. 0.22; max. 3.13)	±0.54 (min. 0.05; max. 0.98)	±0.54 (min. 0.12; max. 1.56)	±1.14 (min. 0.25; max. 5.67)

3.2. Methods

All lateral cephalograms had been taken under the same conditions with teeth in centric occlusion (CO) and the Frankfort Horizontal plane parallel to the floor. Ear rods defined the position of the head. In addition a nasal support prevented a head rotation during exposure.

The 90 radiographs (45 preoperative (T1) and 45 postoperative (T2)) were hand-traced and analyzed by the same individual (AS) using 0.5 mm lead on a 0.10 mm matte acetate tracing paper. A tracing was made on each cephalogram to digitize all hard (Figure 1) and soft tissue (Figure 2), and cephalomeric points (in total 37 points) according to the definitions (Table 2 and 3). Before digitizing all tracings and landmark were verified by another person (MS). The digitizing was performed using tablet digitizer Numonics AccuGrid (Numonics, Landsdale, Pennsylvania, USA) with a resolution of 1 mili-Inch. To calculate the cephalometric values according to the definitions self-written software was used.

Distances and angular values in lateral cephalograms were computed for assessment of the vertical and sagittal characteristics (Table 4).

According to previous studies the error of method of measuring airway distances under standardized circumstances within 30min is 1.22mm (Malkoc, 2005). Because no standardized natural head position has been implemented and the duration between 2 x-rays was much longer in our retrospective study, it is more likely to assume a higher error of method of about 2- 2.5mm. Other studies have found that in order to have a functional effect on AHI, the airway increase has to be at least 1.5mm (Hasabe, 2011). Considering the error of method and the needed clinical effect a value of 4mm was chosen for the power analysis:

Power analysis

Two versions of power analysis for one-way ANOVA were computed. One of them designed to find differences, and the other one to find equivalences between the groups. Assuming, that the pooled standard deviation for Diff p is equal 4mm and the required power is 80%, 26 patients in each of the A, B, C and D groups (total 104 patients) have to be recruited in order to discover relevant differences of 4mm between the groups.

Assuming that the pooled standard deviation for Diff p is equal 4mm and the required power is 95%, 39 patients in each of the A, B, C and D groups (total 156 patients) have to be recruited in order to identify relevant equivalence of 4mm between the groups.

Figure 1: Lateral cephalometric landmarks

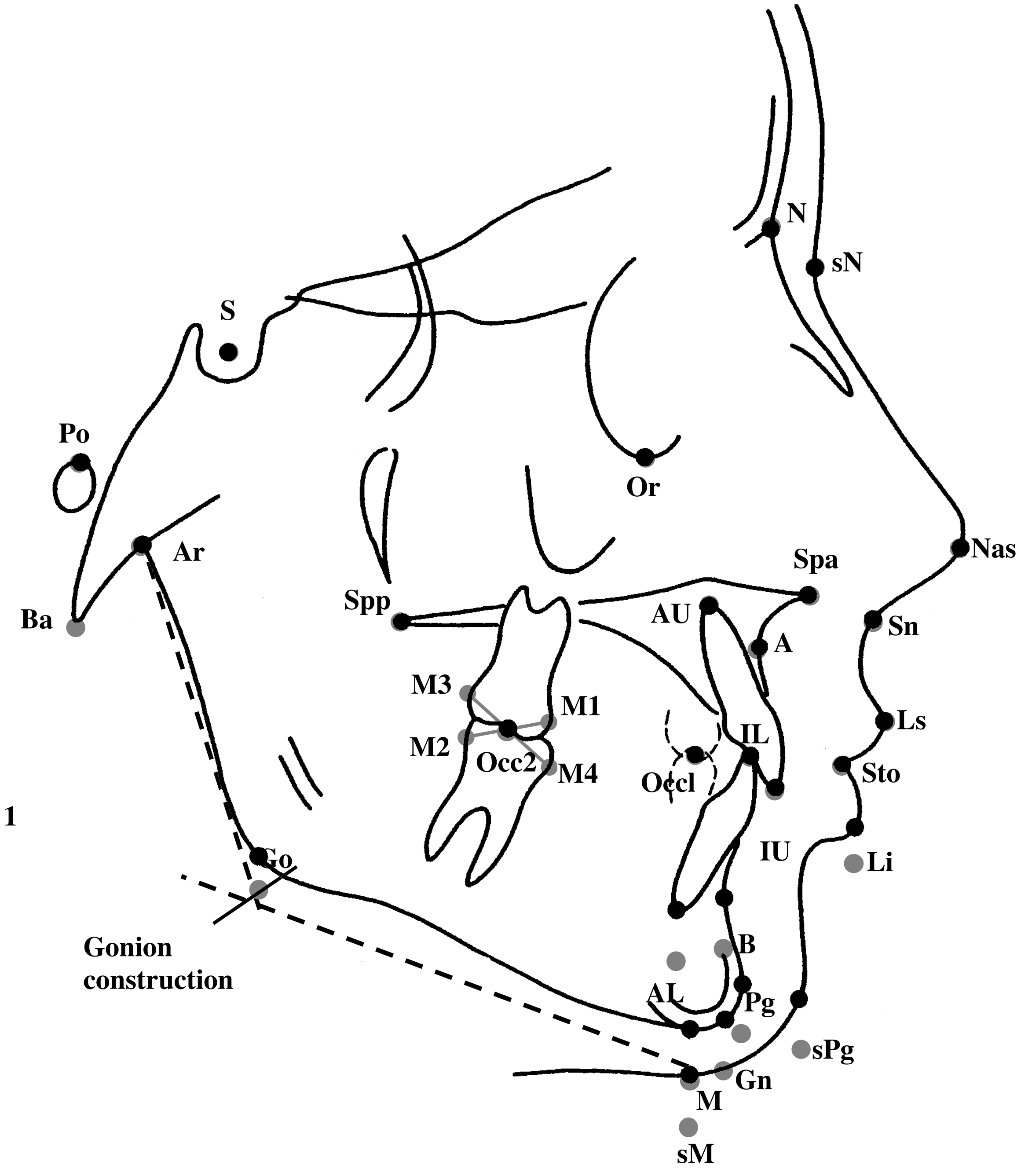

Table 2: Definition of the hard and soft tissue landmarks in the lateral cephalometric analysis

Or	Orbitale	Deepest point on the infraorbital margin. The midpoint is used where double projection gives rise to two projections (Björk, 1947)
S	Sella	Center of the sella turcica. The midpoint of sella turcica arbitrarily determined (Higley, 1954)
Po	Porion	Top of external ear canal (Ricketts, 1960)
Ar	Articulare	Point of intersection of the dorsal contour of processus articularis mandibulae and os temporale (Björk, 1947)
Go	Gonion	Point on the curvature of the angle of the mandible located by bisecting the angle formed by Lines tangent to posterior ramus through Articulare and the inferior border of the mandible through Menton (Jacobsen & Caufield, 1985)
Me	Menton	Move a line parallel to Frankfort Horizontal plane (FH) where it first touches the inferior border of the symphysis of the mandible (Jacobsen & Caufield, 1985)
Gn	Gnathion	Point of the bony chin located on the midline perpendicular of the Pogonion-Menton line (Jacobsen & Caufield, 1985)
Pg	Pogonion	Move the perpendicular line to FH where it first touches the chin (Jacobsen & Caufield, 1985)
B	Point B	Deepest midline point on the mandible between infradentale and Pogonion (Downs, 1948)
LIA	Lower incisor apex	Root apex of the most prominent lower incisor (Bhatia & Leighton, 1993)
N	Nasion	Suture between the fontal and nasal bones (Downs, 1948)
ANS	Anterior nasal spine	Most anterior point of the nasal floor; tip of premaxilla on midsagittal plane (Sassouni, 1971)
A	Point A	Deepest midline point on the premaxilla between the anterior nasal spine and prosthion (Downs, 1948)
PNS	Posterior nasal spine	Most posterior point on the contour of the bony palate (Sassouni & Setareanos, 1974)
UIA	Upper incisor apex	Root tip of the maxillary central incisor. In cases where the root is not yet completed, the midpoint of the growing root tip is marked (Bhatia & Leighton, 1993)
Is	Incision superius	Mid-point of the incisal edge of the most prominent central incisor (Björk, 1947)
Ii	Incision inferius	Mid-point of the incisal edge of the most prominent upper central incisor (Björk, 1960)
M1	Molar point 1	Most mesial point of the upper first molars (Zimmermann-Schildknecht et al., 2011)

M2	Molar point 2	Most distal point of the lower first molars (Zimmermann-Schildknecht et al., 2011)
M3	Molar point 3	Most mesial point of the upper first molars (Zimmermann-Schildknecht et al., 2011)
M4	Molar point 4	Most distal point of the lower first molars (Zimmermann-Schildknecht et al., 2011)
Occ1	Occlusale 1	Midpoint of the tip of the first premolar or canine of the upper and lower jaw (Zimmermann- Schildknecht et al., 2011)
Occ2	Occlusale 2	Intersection of the UM1-LM2-line with the UM2-LM1 line (Zimmermann- Schildknecht et al., 2011)
St	Stomion	Median point of the oral embrasure when the lips are closed (Chaconas, 1980)
Nas	Nasale et	Most prominent point of the nose tip (Zimmermann- Schildknecht al., 2011)
sPg	Soft tissue Pogonion	Most prominent point of the soft tissue chin (Zimmermann- Schildknecht et al., 2011)
sN	Soft tissue nasion	Deepest point on the concavity overlying the area of the frontonasal line. Point of tangent of the soft tissue profile with a perpendicular to the Frankfort Horizontal plane (Zimmermann- Schildknecht et al., 2011)
sMe	Soft tissue Menton	Most inferior point on the soft-tissue chin. Point of intersection of the soft tissue profile with a perpendicular to the Frankfort horizontal plane through Menton (Zimmermann-Schildknecht et al., 2011)
LS	Labrale Superius	Most anterior point of the upper lip (Zimmermann- Schildknecht et al., 2011)
LI	Labrale inferius	Most anterior point of the lower lip (Zimmermann- Schildknecht et al., 2011)

Figure 2: Pharyngeal airway landmarks

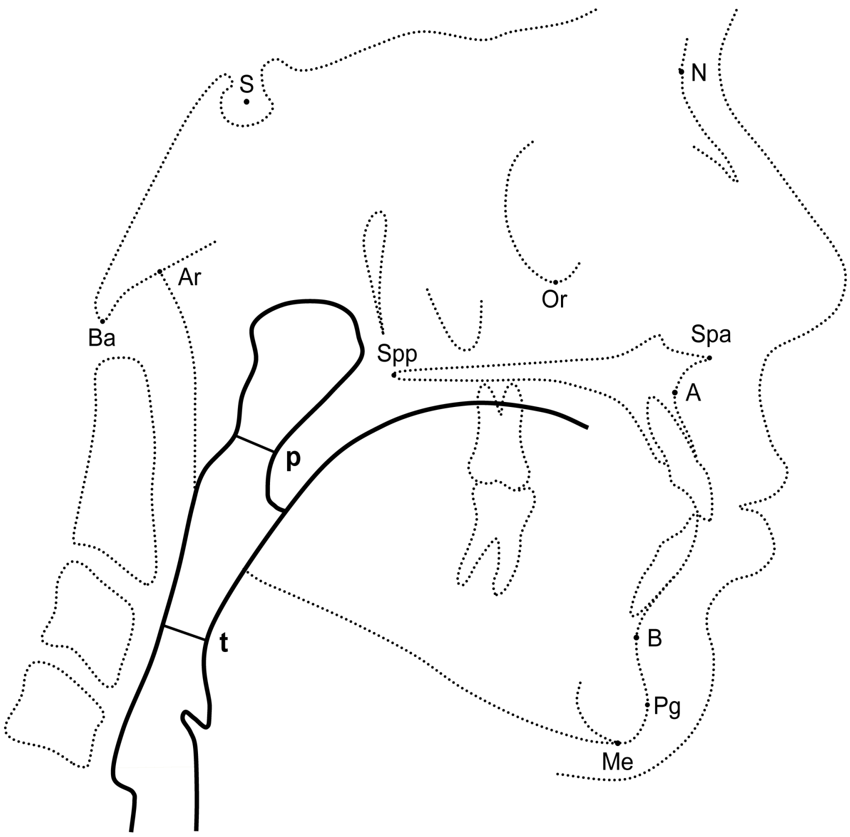

Table 3: Pharyngeal reference points on the lateral cephalogram

p	the shortest distance between the soft palate and the posterior pharyngeal wall
t	the shortest distance between the tongue base and the posterior pharyngeal wall

<u>Table 4</u>: Measurements in lateral cephalometric analysis

Angular skeletal	
Sagittal	*Vertical*
ANB SNA SNB SN/Pg	SpaSpp/Mego Sn/Mego SN/SpaSpp
Linear skeletal	**Airway measurements (linear)**
Sagittal	*Sagittal*
Spp Pg	*p* *t*

Error of method

To assess the method error 15 randomly selected lateral cephalograms were retraced by the same person (AS). Again, another person (MS) verified all tracings and landmark definitions before digitizing. The combined error of landmark location, tracing and digitation was determined using interclass Correlation Coefficient (ICC).

Chin correction

Certain patients had undergone a chin reconstructive surgery, which leads to changes of the chin position. Because some of the lateral cephalometric landmarks can be found on the chin (Point B, Pogonion, Gnathion, Menton) respectively are depending of the chin and its position (soft tissue Pogonion, soft tissue Menton) the change in the horizontal plane must be measured. Therefore a straight line was constructed vertical (90°) to the Frankfurt Horizontal plane (FH) and then another straight line parallel to the FH through the Pogonion. This was done twice on each patient with chin reconstructive surgery twice (T1 preoperative and T2 postoperative) to find out how much the chin had shifted in mm on the horizontal plane. Then the distance of the Pogonion to the line that was constructed vertical (90°) to the FH was measured in all cephalograms pre- and postoperatively (T1 and T2). Next the chin correction was taken into account in the cases of chin reconstructive surgery and the results of the second measurement (T2) showed the true increase or decrease in the horizontal plane of the lower jaw, regardless of the chin surgery.

Statistical methods

Data were coded in Excel and analyzed with SPSS (Version 18). Differences between post- and preoperative angular measurements (SNA, SNB, ANB, SN/PG, SppSpa/MeGo, SN/MeGo and SN/SpaSpp) and linear measurements (Spp, Pg, p and t) were computed. Descriptive statistics such as mean and standard deviation for continuous variables and absolute and relative frequencies for discrete variables were obtained.

Spearman correlations were computed in order to find associations between continuous variables.

One-way ANOVA together with Scheffe post-hoc test was used in order to find differences in mean p and t changes between the four groups (group A Class III, BSSO + LFO; group B Class III, LFO; group C Class II, BSSO + LFO; group D Class II. BSSO). Furthermore a paired t-test was applied to pre- and postoperative measurements of p and t. Results of statistical analysis with p values smaller than 0.05 were considered as statistically significant. The results were interpreted as tendency if the p value was larger than 0.05 and smaller than 0.1.

4. Results

Repeatability

Interclass Correlation Coefficient, revealed that the repeatability for lateral cephalometric measurements is on average 97.3% (range 88.5% - 99.8%). This indicates excellent repeatability of measurements (excellent >90%; good >80%) and the errors can be considered to have an insignificant effect on the results.

Group A (class III, BSSO+LFO) reveals an advancement of the upper jaw (Diff SNA +3.56°, Diff Spp +2.46mm) and a backward shift of the lower jaw (Diff SNB -0.94°, Diff Pg -5.25mm). The vertical dimension shows an increase (Diff SppSpa/MeGo +1.15°, Diff SN/MeGo +1.2°) and the pharyngeal airway space an enlargement (Diff p +1.35mm, Diff t +0.5mm).

In Group B (class III, LFO) the maxilla advances similarly (Diff SNA +3.25°, Diff Spp +3.91mm). Even though no surgical intervention has been carried out in the lower jaw, the chin point also moves backward, due to the downward rotation of the mandible (Diff SNB -0.99°, Diff Pg -1.23mm). Changes in the vertical dimension are contradictory (Diff SppSpa/MeGo -1.75°, Diff SN/MeGo +4.52°), but can be explained by the forward and downward rotation of the maxilla (reducing SppSpa/MeGo) and the backward rotation of the mandible (increasing total vertical dimension). Other than in the first group, the airway space behind the tongue changes just a bit (Diff t +0.3mm) and remains stable behind the soft palate (Diff p +0.01mm).

Group C (class II, BSSO+LFO) reveals an advancement of the maxilla, as well as an advancement of the mandible (Diff SNA +1.13°, Diff Spp +1.62mm, Diff SNB +2.62°, Diff Pg +2.85mm). Vertical dimension decreases (Diff SppSpa/MeGo -1.94°, Diff SN/MeGo -2.95°), while the pharyngeal airway space increases (Diff p +1.87mm, Diff t +0.78mm).

Group D (class II, BSSO) is the only group where the upper jaw remains unchanged (Diff SNA -0.14°, Diff Spp -0.62mm). The advancement of the lower jaw is less distinct than the chin point itself (Diff SNB +2.82°, Diff Pg +2.25mm). Both, vertical dimension (Diff SppSpa/MeGo +2.84°, Diff SN/MeGo +4.1°) and airway space increase (Diff p +2.64mm, Diff t +2.34mm) (Table 5).

Table 5: Mean changes pre- and postoperative (T2- T1), standard deviation for the 4 groups

	Skeletal class III		Skeletal class II	
	A	B	C	D
Surgery	BSSO + LFO	LFO	BSSO + LFO	BSSO
n	12	11	13	8
Numbers of chin correction (N cc)	7 (58%)	1 (9%)	9 (69%)	4 (50%)
Diff SNA [°] Sd [°]	3.56 ± 1,45	3.25 ± 2.71	1.13 ± 3.67	0.14 ± 1.11
Diff SNB [°] Sd [°]	-0.94 ± 2.87	-0.99 ± 1.78	2.62 ± 2.18	2.82 ± 2.24
Diff SppSpa/MeGo [°] Sd [°]	1.15 ± 6.69	-1.75 ± 6.94	-1.94 ± 3.82	2.84 ± 5.29
Diff SN/MeGo [°] Sd [°]	1.2 ± 15.15	4.52 ± 6.34	-2.95 ± 8.82	4.1 ± 4.71
Diff ANB [°] Sd [°]	3.55 ± 4.04	4.24 ± 2.32	-1.51 ± 2.78	-2.66 ± 2.24
Diff p [mm] Sd [mm]	1.35 ± 3.51	0.01 ± 3.55	1.87 ± 5.04	2.64 ± 2.90
Diff t [mm] Sd [mm]	0.50 ± 4.40	0.30 ± 3.92	0.78 ± 2.74	2.34 ± 1.87
Diff Spp [mm] Sd [mm]	2.46 ± 3.13	3.91 ± 4.18	1.62 ± 2.92	-0.62 ± 1.41
Diff Pg (mandibular corpus and chin) [mm]	-1.50 ± 6.50	1.10 ±7.00	8.80 ± 5.80	5.70 ± 5.40
Diff Pg (mandibular corpus only) [mm] Sd [mm]	-5.25 ± 5.01	-1.23 ± 9.55	2.85 ± 6.57	2.25 ± 8.12
Chin correction [mm]	6.4. ± 3.8	8.7 ± 1.4	11.1 ± 3.1	6.9 ± 5.5

Diff SNA: difference SNA angle postoperative (T2) and preoperative (T1) [degree]

Diff SNB: difference SNB angle postoperative (T2) and preoperative (T1) [degree]

Diff SppSpa/MeGo: difference gonial angle postoperative (T2) and preoperative (T1) [degree]

Diff SN/MeGo: difference SN/MeGo angle postoperative (T2) and preoperative (T1) [degree]

Diff ANB: difference ANB angle postoperative (T2) and preoperative (T1) [degree]

Diff p: difference distance UP-phw2 postoperative (T2) and preoperative (T1) (UP: point on the posterior aspect of tongue closest to the dorsal pharyngeal wall; phw2: point on the dorsal pharyngeal wall closest to UP) [mm]; pooled standard deviation= 3.5

Diff t: difference distance TB-phw1 postoperative (T2) and preoperative (T1) (TB: point on the posterior aspect of the tongue closest to the dorsal pharyngeal wall; phw1: point on the dorsal pharyngeal wall closest t TB) [mm]; pooled standard deviation= 4

Diff Spp: difference point Spina posterior postoperative (T2) and preoperative (T1) on xy-coordinate system (x: straight line between Orbita floor (Or) and Sella (S) (Frankfort Horizontal plane); y: at right angles with Or-S [mm] in the horizontal plane.)

Diff Pg: difference point Pogonion postoperative (T2) and preoperative (T1) on xy-coordinate system (x: straight line between Orbita floor (Or) and Sella (S)(Frankfort Horizontal plane); y: at right angles with Or-S [mm] in the horizontal plane.) (Chin correction were taken into account)

sd: Standard Deviation

Correlation analysis

Comparing the longitudinal changes (T1 preoperative-T2 postoperative) revealed following correlations:

Diff ANB showed a positive statistically significant correlation to Diff Spp (CC 0.367, p 0.015), as well as a negative statistically significant correlation to Diff Pg (-0.341). A positive and statistically significant correlation was found between Diff t and Diff p (0.412). There was also a tendency for a positive correlation to SppSpa/MeGo
(-0.264).

No other significant correlation was found. The measurement of the vertical dimension (SppSpa/MeGo) showed only a weak tendency to the changes in the ANB angle but no correlation to the changes of the pharyngeal airway space. Diff t and Diff p revealed no correlation to the other skeletal measurements (Table 6).

Table 6: Correlations between the longitudinal changes of skeletal and airway measurements

			Diff SppSpa/MeGo	Diff ANB	Diff p	Diff t	Diff Spp	Diff Pg
Spearman`s rho	Diff SppSpa/MeGo	CC	1.000	-0.264	0.157	0.097	0.075	0.142
		sig.		0.092	0.321	0.539	0.638	0.371
		N	42	42	42	42	42	42
	Diff ANB	CC	-0.264	1.000	-0.213	-0.111	**0.367***	**-0.341***
		sig.	0.092		0.171	0.478	0.015	0.025
		N	42	43	43	43	43	43
	Diff p	CC	0.157	-0.213	1.000	**0.412****	0.127	-0.076
		sig.	0.321	0.171		0.005	0.412	0.625
		N	42	43	44	44	44	44
	Diff t	CC	0.97	-0.111	**0.412****	1.000	-0.102	0.048
		sig.	0.539	0.478	0.005		0.510	0.759
		N	42	43	44	44	44	44
	Diff Spp	CC	0.075	**0.367***	0.127	-0.102	1.000	0.098
		sig.	0.638	0.015	0.412	0.510		0.525
		N	42	43	44	44	44	44
	Diff Pg	CC	0.142	**-0.341***	-0.076	0.048	0.098	1.000
		sig.	0.371	0.025	0.625	0.759	0.525	
		N	42	43	44	44	44	44

* correlation is significant at the 0.05 level (2-tailed)
** correlation is significant at the 0.01 level (2-tailed)

Diff SppSpa/MeGo: difference SppSpa/MeGo angle postoperative (T2) and preoperative (T1) [degree]
Diff ANB: difference ANB angle postoperative (T2) and preoperative (T1) [degree]
Diff p: difference distance UP-phw2 postoperative (T2) and preoperative (T1) (UP: point on the posterior aspect of tongue closest to the dorsal pharyngeal wall; phw2: point on the dorsal pharyngeal wall closest to UP) [mm]
Diff t: difference distance TB-phw1 postoperative (T2) and preoperative (T1) (TB: point on the posterior aspect of the tongue closest to the dorsal pharyngeal wall; phw1: point on the dorsal pharyngeal wall closest t TB) [mm]
Diff Spp: difference point Spina posterior postoperative (T2) and preoperative (T1) on xy-coordinate system (x: straight line between Orbita floor (Or) and Sella (S)(Frankfurter Horizontal); y: at right angles with Or-S) [mm]
Diff Pg: difference point Pogonion postoperative (T2) and preoperative (T1) on xy-coordinate system (x: straight line between Orbita floor (Or) and Sella S) (Frankfurter Horizontal); y: at right angles with Or-S) [mm] (Chin correction was taken into account)
CC: Correlation Coefficient
sig: Significant (2-tailed)
N: numbers of cases with non-missing values

One-way ANOVA

According to one-way ANOVA there is no evidence that there are differences in Diff p (p= 0.552) and Diff t (p=0.666) in relation to the four groups A, B, C and D (group A Class III, BSSO + LFO; group B Class III, LFO; group C Class II, BSSO + LFO; group D Class II BSSO).

The pooled standard deviation for Diff t and Diff p were estimated to be 3.5 and 4 respectively.

Paired t-test

According to the paired t-test there is a change in p measurements between pre- and postoperative time points: 1.4, 95% CI (0.2; 2.6), p=0.022. There is no evidence that there is a change in t measurements between the pre- and postoperative time points: 0.87, 95% CI (-0.2; 1.9), p=0.101.

5. Discussion

Even though the lateral cephalogram has its limitations, it is a standard procedure in orthodontic and orthognathic surgery patients. Therefore a predictive link between the initial x-ray and the amount of airway changes, which can be expected after certain skeletal surgical interventions, is of great interest. The conventional lateral cephalogram remains a valuable and reliable diagnostic tool, which has been used in numerous airway studies (Shen, 1994; Malkoc, 2005). It is evident, that the measurements on a two-dimensional radiograph cannot illustrate the transverse dimension or the volume of the airway. Three-dimensional imaging methods, such as cone beam technology, would be preferred to depict such changes. However, even three-dimensional radiographs do not really reveal the full condition under which OSA occurs. In order to take a radiograph under realistic circumstances, the patient would have to be lying in supine position, has to be asleep (or less ideally be sedated), and no drugs or alcohol should be ingested. In addition, the radiograph has to be taken at the same stage of the breathing cycle while inhaling or exhaling.

In comparison to nightly clinical monitoring of oxygen saturation and apnea episodes, all radiographs (including three-dimensional radiographs) can only give a guesstimate of the clinical situation of the airway space. Nonetheless, the lateral cephalogram remains a valuable appliance to evaluate the mean changes for a large number of patients for certain interventions. Considering the small sample size that was available for the assessment of the different surgical interventions in this study, it becomes clear, that the mean changes can be influenced by outlier. Therefore the results and mean changes should be considered only as an estimation of the direction of the changes and not as absolute and accurate values.

In our sample, forward movement of the upper jaw (measured by Diff Spp or SNA-angle) did not have a direct influence on the airway. This is true for the individual correlation of the changes but can also been seen if we look at the mean changes of the different groups. For example group B (only forward displacement of the maxilla in class III cases) exhibited the largest advancement of the upper jaw but no change in distance p or t. On the other side, group D (only forward displacement of the mandible in class II cases) exhibited no change in the upper jaw but a large increase of distance p and t, indicating a substantial influence of the lower jaw position on the airway.

The assessment of the true forward or backward displacement of the lower jaw has been complicated through the additional chin correction in some of the cases. But in contrast to the displacement of the upper jaw, an effect of the airways was apparent on the group level. For example group D, with a large forward movement of the mandible, showed also an increase of airway dimensions. Whereas Group B with no surgical intervention in the lower jaw also revealed almost no changes of the airways. But also in the lower jaw a direct individual correlation of the displacement of the airway changes could not be established. The reasons might be the small number of cases or the difficult assessment of the true sagittal and vertical displacement of the lower jaw.

In our sample the advancement of the mandible seems to affect the dimensions of the airway more than the advancement of the upper jaw. However, it is important to note, that a link between the airway and the type of surgical intervention can only be seen at the group level, whereas looking at individual cases could not reveal any correlations. Therefore, it is difficult to prove future airway increases for individual patients at the stage of orthognathic surgery planning, as the outcome may be different or much smaller than expected.

Not only sagittal movements of the jaw have to be considered but also an increase or decrease of the vertical dimension. For example, an increase of the vertical dimension with a backward rotation of the lower jaw might decrease the airway. However, in our sample, no correlations between the vertical dimensions (Diff SppSpa/MeGo and Diff SN/MeGo) and the airways can be found, but because of the small sample size cannot be ruled out completely either.

The main goal of this study was to find out, if there is a correlation between different surgical interventions and their dimension of skeletal displacement of the jaws and the change of the pharyngeal airway space measured on a lateral cephalograms. The measurements have to be interpreted with caution because of the following possible confounders: individual patient response, different operators with different techniques, variability of treatment outcome, timing of x-ray after surgery, different head- or tongue posture during x-ray. But at least at the group level it can be summarized, that an advancement of the lower jaw has on average a positive effect on the airways while the same cannot be said for surgical interventions of the upper jaw.

In order to improve further studies, a prospective study design, standardized three-dimensional radiographs in a supine position, while the patient is sedated and a higher number of patients would be necessary, on account of the large individual variations. And even under ideal circumstances it is very likely that no clear and direct correlation between the amount of skeletal changes and the amount of airway changes can be expected. It seems that the underlying mechanism of the link between those two is more complex on account of present data suggests. One of the reasons could be the individual activity of the airway dilating muscles (awake or asleep) that always have to compensate the negative intraluminal pressure developed during high velocity airflow in a flexible tube, such as the pharyngeal airway.

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